NOV 22 1967

Internal Note No. 67-FM-171

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 67-FM-171

November 13, 1967

THE LUNAR LANDING MISSION SMRCS PROPELLANT BUDGET AS DEFINED FOR THE CONFIGURATION CONTROL BOARD

By Consumables Analysis Section

(This document supersedes 67-FM-155 dated October 20, 1967)

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

(NASA-TM-X-69798) THE LUNAR LANDING MISSION SMRCS PROPELLANT BUDGET AS DEFINED FOR THE CONFIGURATION CONTROL BOARD (NASA) 33 p

N74-70681

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PROJECT APOLLO

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MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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By Consumables Analysis Section

SUMMARY

Recent evaluations of the propellant required to rescue the lunar module (LM) has necessitated that the planned nominal service module reaction control system (SMRCS) propellant budget for the lunar landing mission be reviewed. Propellant budget review meetings were conducted by the Apollo Spacecraft Project Office with the Guidance and Control, Flight Crew Support, and Mission Planning and Analysis Divisions participating. The meetings resulted in guidelines for computing SMRCS propellant budgets.

The SMRCS propellant budget presented in this report was constructed from these guidelines. It has been presented to the Configuration Change Board (CCB), which has requested that any changes be coordinated with the Consumables Analysis Section of the Mission Planning and Analysis Division.

The SMRCS propellant budget resulting from these guidelines indicates that the nominal lunar landing mission can be flown without exceeding the available propellant.

INTRODUCTION

In preparing a preliminary propellant budget, basic assumptions must be made in order to define a propellant usage profile. The recent evaluation of propellant requirements for LM rescue has necessitated that the basic assumptions and guidelines for predicting SMRCS budgets be reviewed. A series of meetings was conducted by the Apollo Spacecraft Project Office to review the basic assumptions and techniques used to compute preliminary SMRCS budgets. The meetings were attended by designated personnel from Guidance and Control, Flight Crew Support, and Mission Planning and Analysis Divisions. It was concluded that the following areas must be controlled to establish a consistent baseline for computing propellant budgets:

(a) Mission timeline describing the flight sequence of events.

(b) Propellant consumption data for the various modes of operation.

(c) Procedures for operation of the spacecraft systems.

Using the above information as initial guidelines a review of the current mission timeline, propellant consumtion data, and procedures for system operation for the lunar landing mission was conducted. This review resulted in establishing the following guidelines:

(a) All command and service modules (CSM) maneuvers will be three-axis (auto or manual) at a rate of 0.2 deg/sec unless otherwise defined.

(b) Initial docked CSM weight was assumed to be 96 000 lb.

(c) All inertial measurement unit (IMU) alignments will consist of coarse and fine alignment three-axis attitude maneuvers.

Using the guidelines, the SMRCS propellant budget presented in this document was constructed and presented to the Apollo Configuration Change Board. The Configuration Change Board authorized that this budget be placed under configuration control and that any change must be coordinated with the Consumables Analysis Section, who will present the effects to the board.

Therefore, this document will be used as an instrument for coordinating and maintaining SMRCS propellant usage for the lunar landing mission. The established guidelines, sequence of events, and procedures of operation for a mission are subject to revision any time prior to final flight review. Any alterations to the planned mission will effect some area of the spacecraft's consumables budget. These alterations are to be reviewed by the Consumables Analysis Section. The Consumables Analysis Section has the responsibility to coordinate, maintain, and document all consumables budgets for the Apollo project (ref. 1). The Astronaut Office, Flight Crew Support, Guidance and Control, and Flight Control Divisions have been requested to support the Consumables Analysis Section in maintaining the consumables budgets. Changes should be submitted to R. H. Brown, head, CAS, office code FM-741, extension 4581.

This document identifies the mission sequences requiring propellant usage and describes the assumptions and evaluates problem areas. Crew precedures and spacecraft system operations are also described. Note that these procedures do not define mission rules or final modes of operation, but are only an attempt to control the configuration of the SMRCS propellant profile and alert the user to the techniques for predicting propellant consumption.

ABBREVIATIONS

Acc Comm	acceleration commands
Auto	automatic
CSM	command and service modules
DB	deadband
g.e.t.	ground elapsed time
G&N	guidance and navigation
IMU	inertial measurement unit
LM	lunar module
LOI	lunar orbit insertion
Max	maximum
MCC	midcourse correction
Min	minimum
P	pitch
PTC	passive thermal control
R	roll
RCAH	rate command attitude hold
SCS	stabilization control system
SCT	scanning telescope
SMRCS	service module reaction control system
SPS	service propulsion system
TEI	transearth injection
TPF	terminal phase finalization
Y	yaw

THE SMRCS PROFILE

Using the guidelines described in the introduction and the lunar landing mission timeline (ref. 2) the SMRCS propellant profile was constructed (table I). Table I presents the mission timeline used to construct the SMRCS profile (fig. 1), and describes the event using SMRCS propellant. The primary and backup guidance control mode was also defined with the propellant requirements for each mode. The propellant consumption for translunar, lunar orbit, and transearth is presented in table II.

It is interesting to note that less than 170 lb of propellant was used for the translations, and the remaining was used for attitude control. This reflects the impracticability of referencing the SMRCS propellant to velocity.

A description of the crew procedures and spacecraft operations incorporated used in planning this budget follows. Contingencies for which propellant has not been allotted are then described.

LLM SMRCS Guidelines

Transposition, docking, and LM extraction.- A CSM separation velocity of 1 fps was chosen to insure that an unexpected movement of the S-IVB would not cause recontact. If it becomes necessary to have continuous hydrogen venting on the S-IVB, the 1-fps separation velocity may have to be increased. A 1-fps -X translation is allotted to keep the separation distance from increasing, and transposition turnaround is then accomplished by a 5 deg/sec manual pitch maneuver. A lower pitch rate could save significant SMRCS propellant; however, at the 5 deg/sec rate this maneuver would take 36 seconds, and it is deemed beneficial to observe the S-IVB as soon as possible. A 60° roll maneuver at 5 deg/sec is then performed to align the CSM in the docking attitude. The return to the S-IVB is made by a ±0.5-fps translation. At this stage, all SMRCS thruster performance will have been verified by the ±X translations and 60° roll maneuver. Index and docking are assumed to be performed by the procedure outlined by the Langley studies (ref. 3).

The LM withdrawal is made by firing the -X jets for 10 seconds (maximum allowable time due to exhaust impingement on LM). Resulting separation velocity is 1.25 fps. An additional 1.75 fps is added at a later time to insure adequate S-IVB separation distance. It may be necessary to add an orientation maneuver for proper separation from the S-IVB or thermal orientation. In this case the additional separation velocity could be accomplsihed by a minimum impulse SPS burn.

In the lunar phase of flight the LM is assumed to do the active separation and docking and the CSM provides only attitude hold. Studies are being conducted to determine the effects on the LM guidance and landing accuracy if the LM does the separation maneuver. If the CSM is required to do the separation maneuver an additional 5.0 lb of propellant will be added to the SMRCS profile.

Navigation sightings.- In the translunar phase, one navigation sighting is scheduled prior to the second MCC, and, in the transearth phase, one navigation sighting is scheduled prior to each of the two MCC's. These sightings will be made to verify vehicle trajectory characteristics and to provide onboard navigation backup capability. One attitude maneuver is required from the thermal attitude position to locate the landmark in the telescope. Fine positioning of the spacecraft for sighting the landmark in the sextant requires a trim equivalent to a 0.05 deg/sec maneuver. One additional trim maneuver is allowed for changing landmarks. Three star sightings are made on each of the two landmarks.

Five navigation sightings are scheduled during the lunar orbit phase, and seven observation maneuvers are scheduled for the descent, lunar stay, and ascent activity. Two landmark navigation sightings were made after LOI to determine the CSM/LM lunar orbit ephemeris. The other three sightings are scheduled to update and refine state vector data to insure the maximum possible accuracy.

One orientation maneuver in which the vehicle is oriented with the X axis parallel to the orbit-rate vector is required to prepare for sightings. A roll rate equal to orbit rate is established, then retarded and advanced to pick up landmarks at different declinations. All other line-of-sight motion is provided by moving the optics.

Midcourse corrections.- Two MCC's are scheduled for the translunar phase of flight using the SPS. The magnitude of the SPS burns were assumed to be from 50 to 1 fps. A SMRCS trim burn of 1 fps was allotted to null errors. The 3σ cross-axis velocity pointing error for the CSM/LM fully loaded configuration is 2.5 fps for a 50-fps SPS burn (7-seconds duration).

No propellant is allotted for lunar orbit correction prior to LM separation. Should the lunar orbit insertion (LOI) burn induce error into the planned lunar orbit, it may become necessary to make a lunar orbit trim correction. The budget does include a nominal plane change using the SPS. The CSM plane change may be as high as 2° (approximately 200 fps). Corrections below 5.5 fps will require SMRCS propellant.

Two midcourse corrections are planned for transearth flight. The first correction is a planned SPS burn requiring a two-jet 20-second ullage. The second correction is a 5.0-fps SMRCS burn.

Figure 2 presents the change in velocity (ΔV) capability using the 3000-lb-sec minimum impulse technique. This figure indicates that the minimum SPS burn are 1-fps translunar, 5.5-fps lunar orbit (CSM only), and 6.5-fps transearth.

IMU alignments.- Propellant is allocated for thirteen IMU alignments (three translunar, seven lunar orbit, and three transearth). IMU coarse alignments are calculated as three-axis manual maneuvers to locate at least two navigation stars in the SCT. The fine alignments were made using three-axis automatic maneuvers. It is assumed that by using three-axis attitude maneuvers, gimbal lock attitudes will be avoided.

Thermal cycling.- Results of recent studies have caused slight modifications to the thermal cycling procedure. The procedure still calls for orientation to thermal attitude, attitude hold in pitch and yaw while spinning up in roll, and recycling when coning angle becomes too great. The modifications include (1) using G&N control for initial orientation where possible, (2) spinning at 0.3 deg/sec, (3) recycling at particular time intervals rather than using the telescope to denote coning angle deviation, and (4) including three-axis maneuvers for trimming attitude where a single-axis pitch maneuver had been included previously. These techniques have been adopted for translunar coast, and will be used for transearth coast. Initial orientation may require an offset angle to compensate for cross-coupling torques. The time interval for translunar recycling is 20 hours for translunar operations and 4 hours for transearth.

Lunar orbit thermal control is assumed satisfied by the attitude hold during the rest periods and by the attitude maneuvering during the work period.

Ullages.- Ullage maneuvers are not required until after the LOI SPS burn. Two-jets pitch or yaw ullages are used alternately for the remaining SPS burns. Each two-jet ullage is calculated for a burn time of 20 seconds. It is suggested that the 20-second settling time be used for all CSM undocked SPS burns unless propellant is extremely critical or the SPS burn schedule is non-nominal. Two-jet ullages were chosen for quad management and propellant saving. If these requirements are not necessary, it is suggested that a nominal 15-second ullage (four-jet ullage) be made.

Entry preparation and separation.- Entry preparations included orienting the -Z axis toward the sun to cool the forward heatshield. After the cold-soak period the CSM is re-oriented by a three-axis maneuver to the separation attitude. Initiation of the separation programers fires the -X jets until propellant or electrical power is depleted. Two seconds after separation, four roll jets (9, 11, 13 and 15) are fired for 5.5 seconds for spin stabilization. Propellant is allowed for a 10-fps separation velocity increment.

Propellant available for mission planning.- The maximum capacity of the SMRCS tank system is 1360 lb loaded at 65°F. Temperature and loading dispersions could cause a 24-lb decrease in propellant availability, and the trapped and unexpelled propellants an additional 36-lb deficient. This would result in a maximum propellant available (minimum deliverable) of 1300 lb.

The SMRCS tanks are designed for propellant consumption at a 2-to-1 mixture ratio. Considerable SMRCS activity is done at mixture ratios other than 2-to-1, particularly for attitude maneuvers. Until a detailed attitude timeline becomes available, the mixture ratio uncertainty caused by a non-steady-state operation will be estimated on attitude maneuver activity. The mixture ratio uncertainty for this budget was estimated to be 40 lb.

Spacecraft 104 and subsequent spacecrafts will be equipped with solenoid isolation valves downstream from the primary and secondary SMRCS propellant tanks. The primary advantages of these valves are the capability to run the primary tanks dry and provide a check point for the quantity gaging system (ref. 4). When the primary system is depleted, the propellant in the secondary system is gaged to ± 6.3 percent (28 lb total system). The primary system has approximately 784 lb of usable propellant. Table I predicts that the nominal mission usage is 409 lb which indicates that the secondary system would not be activated unless a LM rescue was required. The activation would probably occur during the terminal phase of the rendezvous (TPF), which is an undesirable time for the pilot. Should the pilot elect to activate the secondary system prior to TPF, the gaging uncertainty would increase, and, if any tank in the secondary system should be in a failed condition, all propellant in the quad could be lost.

The effects of the loading and temperature dispersions, trapped and unexpelled propellants, mixture ratio uncertainty, and gaging accuracy result in 1232 lb of propellant being available for mission planning (table II).

Lunar Mission Contingency

Lunar module rescue.- The Guidance and Control Division (G&CD) has conducted a manned simulation to determine the SMRCS fuel required to rescue a dead LM in lunar orbit. An internal note is being prepared by G&CD which discusses the simulated rendezvous trajectories, onboard state vector errors, simulation crew procedures, and propellant budget requirements (ref. 5). Table I presents the SMRCS rescue propellant requirements as defined by the G&CD simulations. Figure 1 presents the LM rescue effects on the SMRCS propellant profile for both primary and secondary guidance modes.

Quad failure.- Gemini flights II, III, and VI were the only spacecrafts in the Gemini flight program that did not experience RCS difficulty in some manner, and these flights were all of short duration. This experience signals that caution should be taken in planning for jet or quad failure. It is interesting to note that these quads are not completely redundant. Single point failures in the oxidizer or fuel inline filters and the helium tank could fail one entire quad. A quad failure will result in the loss of one-fourth of the propellant remaining. A more significant result is that only one-half of the propellant remaining will be available for translation and ±Y or ±Z translation may also require a roll maneuver. It is quite apparent that a quad failure would endanger a LM rescue. Figure 3 presents the propellant profile with a quad that has failed after lunar module landing.

SMRCS checkout.- The SMRCS checkout can be verified on the launch pad by visual observation and sound. However, should an orbital checkout prior to S-IVB separation be required, it would be necessary to operate in the minimum impulse mode and be over a tracking station to verify solenoid valve operation. Checkout would probably be conducted in the direct mode.

Attitude hold requirement in lunar orbit.- The SMRCS budget as presented in table III carries propellant allowance for the SCS wide deadband attitude hold during the rest periods. The attitude hold was based on the nebulous requirements for communication and thermal constraints in the influence of the large lunar gravity gradient. This procedure also increases the electrical power requirement for SCS operation.

Spacecraft maneuver rates.- In order to reduce propellant consumption as much as possible, maneuver rate has been lowered to 0.2 deg/sec. This is very effective when the LM is docked to the CSM. After separation and particularly in transearth coast, the total propellant requirement for maneuvering is very small and maneuver rates could be raised to 0.5 deg/sec with little budget impact. During lunar orbit, it may be desirable that higher maneuver rates be used because of limited time available for operations such as landmark sightings. These rates could be raised with minimum impact after CSM/LM separation.

Slosh damping.- Propellant allocations were made for shut-down transient slosh damping after each SPS burn. It was assumed that attitude hold will be inhibited for 10 minutes following the SPS burn to reduce SMRCS propellant required for stabilization. No propellant allowances were made for slosh damping following attitude maneuvers; however, attitude holds in the SCS mode include the effects of gravity gradient and steam venting (ref. 6) in the lunar orbit phase.

Thruster efficiency.- It was assumed that all thrusters operate nominally. Effects of a 3σ low performance or failed thruster were not evaluated. Failure of certain thrusters may cause additional attitude maneuvers or eliminate two jet ullage savings.

CSM communication maneuvers.- It has been assumed that for a nominal lunar landing mission profile, no CSM communication maneuvers will be required. This assumption is based on the prefix that low-bit-rate data will satisfy crew monitoring requirements.

Mass property variations.- Propellant consumption is a function of the center of gravity and moment of inertia. Internal vehicular activity and SPS propellant movements will continuously shift these locations. Recent mass property studies indicate that propellants required for attitude maneuvering during the lunar mission will vary by an average of 12 percent. This study assumes that the propellant remaining is aft of the tanks.

Miscellaneous anomalies.- Other areas which could contribute to the reshaping of the SMRCS profile are

1. Crew procedure errors.
2. Man-in-the-loop simulation results.
3. Trajectory dispersions.
4. Launch window variations.
5. Spacecraft weight growth.
6. SPS trim requirements.
7. MSFN in error or out.
8. Orientation for solar flares.

CONCLUSION

The SMRCS propellant available is adequate to complete the lunar landing mission provided the failure contingencies are not encountered. However, this prediction is subject to changes in the nominal timeline, spacecraft configurations, and procedures of operation.

Should modifications occur in the nominal mission, they will be reported to the Consumables Analysis Section of the Mission Planning and Analysis Division, who have the responsibility for coordination, maintenance, and documentation of all consumable budgets for the Apollo project.

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Launch checkout	SMRCS checkout	--	--	--	--	
Ascent						
0:00	Lift-off to TLI	--	--	--	--	
Transposition & docking	Separation from S-IVB x translation 1 fps	G&N free	SCS Acc Comm	8.0	9.4	SC weight $\approx$ 96 000 lb
	Null translation (0.5 fps)	G&N RCAH	SCS, RCAH	4.0	4.7	
	Turn around at 5 deg/sec	G&N	SCS RCAH, R, Y Acc Comm in pitch	9.1	9.1	2 deg/sec rate would save 5.1 lb
	Null translation (0.5 fps)	G&N RCAH	SCS RCAH	4.0	4.7	
	Return to S-IVB and null at 0.5 fps	G&N RCAH	SCS RCAH	8.0	9.4	
	Roll CSM 60° at 5 deg/sec	G&N free	SCS RCAH P, Y	4.1	4.1	2 deg/sec rate would save 2.5 lb
Index and dock	Index and dock	SCS RCAH	G&N RCAH	26	--	Langley studies (1966 3-sigma value)
4:45	LM extraction (10 sec, 4 jet thrust at 1.25 fps)	SCS RCAH	G&N RCAH	14.0	14.0	Use SCS narrow deadband and obtain added reliability
5:50	Increase separation velocity (1.75 fps)	G&N	SCS	19.6	22.9	
Subtotal						
Accumulative total				96.8		

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Coast	Orient for PTC 3-axis manual (.2 deg/sec)	G&N free	SCS Acc Comm	3.6		All orientation were calculated as 3-axis manual or auto unless otherwise defined. Orientation may actually be 2 axis, R-63, etc.
	Attitude hold for 1/4-hr minimum deadband	SCS RCAH	G&N RCAH at 0.5° DB	0.25	0.12	
	Start PTC	SCS RCAH, P, Y Acc Comm in R	G&N free	.15	.11	
	Stop PTC	SCS Acc Comm	G&N free	.17	.11	Possible to damp rates automatically if gyros can be turned on
IMU alignment						
9:00	Orientation determination 3 axis at 0.2 deg/sec	G&N free	SCS Acc Comm	5.0	5.0	
	Coarse align (use optics)	G&N	SCS	0	0	
	Fine align 3-axis G&N at 0.2 deg/sec	G&N	SCS	3.6	4.1	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
MCC #1						
9:45	Orient for MCC	G&N auto	SCS RCAH	3.6	4.1	
	Attitude hold 0.5° deadband	G&N	SCS	0.12	0.12	
	SPS burn roll control	G&N auto MAX DB	SCS RCAH MAX DB	negli-gible	negli-gible	
	Shut down transient	G&N auto or hold MAX DB	SCS RCAH MAX DB	1.1	1.1	
Subtotal				17.59		
Accumulative total				114.39		
Coast						
9:55	Orient for PTC, start PTC, stop PTC, correct attitude, and start and stop PTC at 66:00 g.e.t.	G&N free	SCS Acc Comm	11.8	11.8	Use G&N 2 axis for first maneuver and SCS 3 axis for second Reorient every 20 hr
Navigational sightings						
(Star-LM)	Initial orientation (3-axis manual)	G&N free and atti-tude hold	SCS Acc Comm RCAH	5.0	5.4	With forethought the crew would have to do very little maneuver-ing if they stop PTC right 2-axis maneuver for RCS fuel.

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
	5 navigational sightings	G&N free MI	SCS MI	3.6	3.9	
IMU alignment						
67:55	Same as first alignment	G&N auto	SCS Acc Comm MI	8.6	9.4	
MMC #2						
68:25	Same as first MCC	G&N auto	SCS Acc Comm RCAH	4.9	5.5	
68:50	RCS cleanup orientation	G&N free RCAH	SCS Acc Comm RCAH	3.6	4.1	
69:05	SMRCS ΔV = 1 fps	G&N RCAH	SCS	11.8	12.9	
Subtotal				49		
Accumulative total				163.39		
Coast						
69:20	PTC, start, stop (includes initial orientation)	G&N auto (as first coast)	SCS Acc Comm (as first coast)	3.6	3.9	
IMU alignment						
76:33	As first alignment			8.6	9.4	As first alignment

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
LOI						
77:03	Orient for LOI	G&N auto	SCS Acc Comm RCAH	3.6	3.9	
77:18	SPS burn roll control	G&N auto	SCS RCAH	0.4	0.4	Digital autopilot thrust vector control 5° deadband
	Shut down transient			1.1	1.1	
Subtotal				17.3		
Accumulative total				180.69		
77:38	Visual orbit checkout (two 3-axis maneuvers) at 0.2 deg/sec	G&N free	SCS Acc Comm	5.2	5.7	
	Rest period-establish attitude 0.2 deg/sec	G&N free switch SCS-RCAH	SCS Acc Comm	3.1	2.5	4.2° DB cost 1.27 lb/hr 1 jet/axis CSM only, includes gravity gradient and SC venting effects. Attitude hold may be required for crew safety.
	Attitude hold		SCS MAX DB	10.8		
IMU alignment						
89:33	Align IMU 0.2 deg/sec	G&N free auto	SCS Acc Comm	6.7	7.8	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Navigational sightings						
(Lunar LM) 89:48	Orient for landmark sightings 3-axis manual, 0.2 deg/sec	G&N free	SCS Acc Comm MI	3.5	3.8	
	Do sightings, use optics	G&N MI	SCS MI	4.6	5.0	
91:33	IMU alignment	G&N free	SCS MI	3.5	--	
91:33	Orient for landmark sighting	G&N free MI	SCS Acc Comm MI	4.6	5.0	
91:48	Landmark sighting			3.5	3.8	
IMU alignment						
93:33	Orientation determination (3-axis manual, 0.2 deg/sec)	G&N free RCAH	SCS Acc Comm RCAH	4.0	4.3	
	Coarse align, use optics	G&N auto		--	--	Maneuver not required
	Fine align	G&N auto	SCS Acc Comm MI	2.6	2.8	
Separation						
94:48	Orient for separation	G&N auto (free?)	SCS Acc Comm	2.6	2.8	Conservative fuel value - maneuver can be made at lower rate

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Subtotal				54.7		
Accumulated total				235.39		
Descent orbit insertion						
95:24	Orient CSM for LM inspection, 3 axis 0.5 deg/sec	G&N RCAH (0.5° DB)	SCS RCAH (0.2° DB)	.8	0	
	Damp separation rates; orient CSM to track LM during descent	G&N free	SCS Acc Comm	.5	.5	Initial acquisition and tracking
Landing site observation	Orient to observe LM; use optics pitch maneuver	G&N	SCS	.8	.6	Pitch maneuver/optics
IMU alignment						
97:33	Orientation, 3 axis 0.2 deg/sec	G&N free	SCS Acc Comm	.8	.18	
	Alignment, coarse and fine - use optics	G&N auto	SCS Acc Comm	--	--	No maneuver required.
Navigational sightings						
97:48	Orient 3 axis	G&N free	SCS Acc Comm	.8	.8	
	Do sightings; use optics	G&N free	SCS Acc Comm	.4	.4	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
IMU alignment						
99:33	Orientation	G&N free	SCS Acc Comm	.8	.8	
Subtotal				4.9		
Accumulated total				240.29		
Navigational sightings	Orientation	--	--	1.2	1.2	
	Visual observation	G&N free RCAH	SCS Acc Comm RCAH	.8	.8	
103:08	Rest period-establish attitude 3-axis maneuver	G&N free RCAH	SCS Acc Comm	.8	.8	
	Attitude hold	SCS MAX DB		10.8	10.8	
111:38	Visual observation	G&N free	SCS Acc Comm	.8	.8	
IMU alignment						
113:48	Orient and coarse, fine align	G&N	SCS	1.4	1.5	Two 3-axis maneuvers at 0.2 deg/sec
Plane change						
114:08	Orient 0.5 deg/sec maneuver	G&N auto	SCS Acc Comm RCAH	1.1	1.25	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
	Ullage - 2 jets, 20 sec	G&N auto	SCS RCAH	14.4	14.4	
	Negligile SPS burn control	G&N auto	SCS RCAH			
	Shut down transient	G&N auto	SCS RCAH	1.1	1.1	
IMU alignment						
115:38	Orient, coarse & fine align	G&N free	SCS Acc Comm	1.4	1.5	Two 3 axis 0.2 deg/sec manual
Navigational sightings						
115:53	Two maneuvers 0.2 deg/sec	G&N free	SCS Acc Comm	1.4	1.5	
LM ascent						
117:42	Orient for LM ascent & track	SCS Acc Comm RCAH	G&N free RCAH	.8	.8	Use SCS as it can be put into hold on per axis basis
Docking						
122:29	Orient and hold while LM docks (0.5° DB)	G&N RCAH free	SCS Acc Comm RCAH (0.2° DB)	4.2	4.4	
LM jettison	LM separation 4 jets, CSM active 1 fps	G&N RCAH	SCS RCAH	2.5	2.7	
123:48	Visual observation 3-axis manual	G&N free RCAH	SCS Acc Comm RCAH	.8	.8	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
125:28	Orient for rest	SCS Acc Comm RCAH	G&N free RCAH	2.2	2.4	Leave G&N and SCS off
	Attitude hold	MAX DB	MAX DB	10.8	10.8	
133:48	Visual observation 3 axis manual			.8	.8	
Subtotal				57.3		
Accumulative total				297.59		
IMU alignment						
135:32	Orient, coarse, fine	G&N auto	SCS Acc Comm MI	.8	.8	
TEI	Orient for TEI (3-axis G&N)	G&N auto	SCS Acc Comm RCAH	.8	.8	
	Attitude hold 15 min 0.5° DB	G&N auto	SCS RCAH (0.2° DB)	.7	1.3	2.62 lbs/hr
	Ullage 2 jets, 10 sec	G&N auto	SCS RCAH	14.4	14.4	
	SPS burn roll control	G&N auto	SCS RCAH	.1	.1	5° DB
	Shut down transient	G&N auto	SCS	1.1	1.1	
Subtotal				17.9	18.4	
Accumulative total				315.49		

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Coast						
136:30	Start, stop PTC twice correct attitude once One orientation 0.1 deg/sec maneuver thermal roll rate 0.3 deg/sec	SCS Acc Comm to orient RCAH-P, Y comm in R during spin up	SCS free	3.2	3.4	
Navigational sightings	Lunar LM-Star - orient axis man at 0.2 deg/sec, trim plus MI requirements	G&N free	SCS Acc Comm MI	.8	.8	
IMU alignment	Orient - 3 axis	G&N free auto	SCS Acc Comm MI	.7	.8	
	Coarse, fine align	G&N auto	SCS Acc Comm MI	.7	.8	
MCC #3	Orient for MCC #3 3 axis 15 min attitude hold	G&N auto	SCS Acc Comm RCAH	.8	.75	
147:15	2 jet, 20 sec ullage	G&N auto	SCS RCAH	14.4	14.4	
	SPS burn roll control and shut down transient	G&N auto	SCS RCAH	1.2	1.1	
Subtotal				21.8		
Accumulative total				337.29		

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Coast	PTC activities to 225:30	SCS Acc Comm to orient RCAH-P, Y and Acc Comm in R during spin up. Correct atti- tude in Acc Comm	G&N free RCAH to null rates correct in free	14.0	14.0	20 orientation at 0.1 deg/sec
Navigational sightings						
215:30	Lunar LM-Star sight orientation plus maneuvers	G&N auto	SCS Acc Comm MI	1.4	1.5	
IMU alignment						
225:30	Orientation, coarse and fine align; use optics	G&N free auto	SCS Acc Comm MI	1.4	1.5	
MCC #4	Orientation, 3 axis plus 15 min 0.5° attitude hold	G&N auto	SCS Acc Comm RCAH (0.2°)	.8 .6	.8 1.3	
	RCS trim - 5 fps	G&N auto	SCS RCAH	18.0	21.0	

TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

Phase time, hr:min g.e.t.	Event	Control mode		RCS propellant, lb		Comments
		Primary	Backup	Primary	Backup	
Coast	PTC activities; 2 orientations	SCS	G&N	2.0	3.2	
Entry preparation						
241:00	Orient heat shield	G&N free RCAH	SCS Acc Comm RCAH	.7	.7	
IMU alignment						
242:05	As above			1.4	1.5	
SM separation						
242:45	Orient for separation 3-axis G&N	G&N auto	SCS Acc Comm	.7	.75	
	CM/SM separation 4 jet X-translation of 10 fps and spin up	SCS auto sep		31.0	31.0	
Subtotal				72.0		
Grand total				409.29		

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TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Continued

[Lunar Module Rescue Requirements]

Event and time	Control mode		RCS fuel		Comment
	Primary	Backup	Primary SXT	Backup LOS	
Orient to CSI attitude	G&N auto	SCS Acc Comm	1.1	1.25	
CSI ullage 119:37	G&N auto	SCS RCAH	13.5	15.3	
SPS shutdown transient	G&N auto	SCS RCAH	1.1	1.1	
CSI trim (3 ft/sec) 119:38	G&N auto	SCS RCAH	12.9	4.8	This might be an unnecessary maneuver because the navigational uncertainties swamp the trim value. SCS does not have capability to display SPS cross axis burn errors.
IMU align 119:42	G&N free, auto	SCS Acc Comm MI, RCAH	1.4	1.5	
Orient to track LM with SXT 119:57	G&N auto	SCS Acc Comm, MI	1.1	1.25	
CDH ullage 120:36	G&N auto	SCS RCAH	13.5	15.3	
SPS shutdown transient			1.1	1.1	
CDH trim (3 ft/sec) 120:37	G&N auto	SCS RCAH	12.9	4.8	Might be unnecessary for same reasons as CSI trim

Change 1
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TABLE I.- LUNAR LANDING MISSION SMRCS BUDGET - Concluded

[Lunar Module Rescue Requirements]

Event and time	Control mode		RCS fuel		Comment
	Primary	Backup	Primary SXT	Backup LOS	
Orient to track LM 120:40	G&N auto	SCS Acc Comm, MI	1.1	1.25	
Orient to TPI burn attitude 120:57	G&N auto	SCS Acc Comm	1.1	1.25	
RCS TPI burn 121:01	G&N auto	SCS Acc Comm	60.8	48.9	If this maneuver is done with SPS, 50.1 lb fuel is saved
TPI burn 121:00			102	77	
TPM/TPF attitude control (3σ) TPM/TPF translational and LOS control (3σ)			323	419	
Station keeping and docking 121:50			45	50	
Total LM Rescue			531	595	

TABLE II.- SUMMARY OF THE SMRCS PROPELLANT BUDGET

FOR THE LUNAR LANDING MISSION

Translunar phase		
Transposition, docking, and LM, lb	97	
Navigation sighting, lb.	9	
Midcourse corrections (two SPS burns and a 1 fps RCS trim), lb.	26	
Lunar orbit insertion, lb.	9	
Thermal cycling, lb.	18	
Three IMU alignments	26	
Total propellant for translunar phase, lb.		185
Lunar orbit phase		
Attitude hold (rest period), lb.	33	
Five navigational sightings, lb.	12	
Coast and LM monitoring, lb.	26	
Separation docking, lb	9	
Plane change, lb	16	
Transearth injection, lb	18	
Seven IMU alignments, lb	13	
Total propellant for lunar orbit phase, lb		127
Transearth phase		
Thermal cycling, lb.	20	
Midcourse corrections (one SPS burn and a 5-fps RCS burn), lb.	36	
Entry preparation and separation, lb	34	
Three IMU alignments, lb	4	
Two navigation sightings, lb	3	
Total propellant for the transearth phase, lb.		97
Total propellant for the lunar landing mission.		409

TABLE III.- SMRCS Propellant Available

Maximum loaded propellant, lb		1360
Unusable		
Loading and temperature dispersions, lb	24	
Trapped and unexpelled, lb	36	
Total unusable, lb	60	
Minimum deliverable propellant, lb		1300
Mixture ratio uncertainty, lb	40	
Gaging accuracy, lb	28	
Total, lb	68	
Total propellant available for mission planning, lb		1232

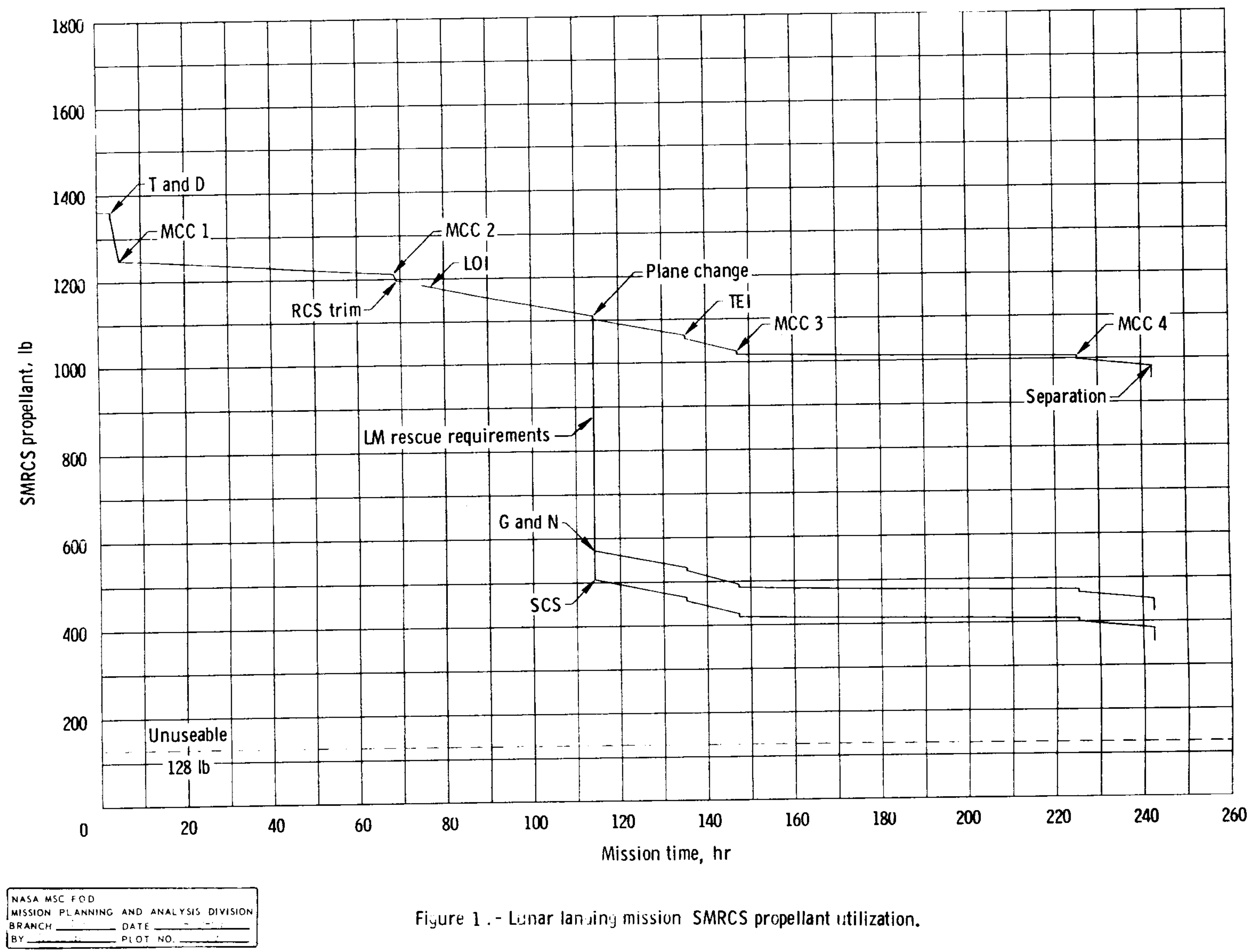

Figure 1 . - Lunar landing mission SMRCS propellant utilization.

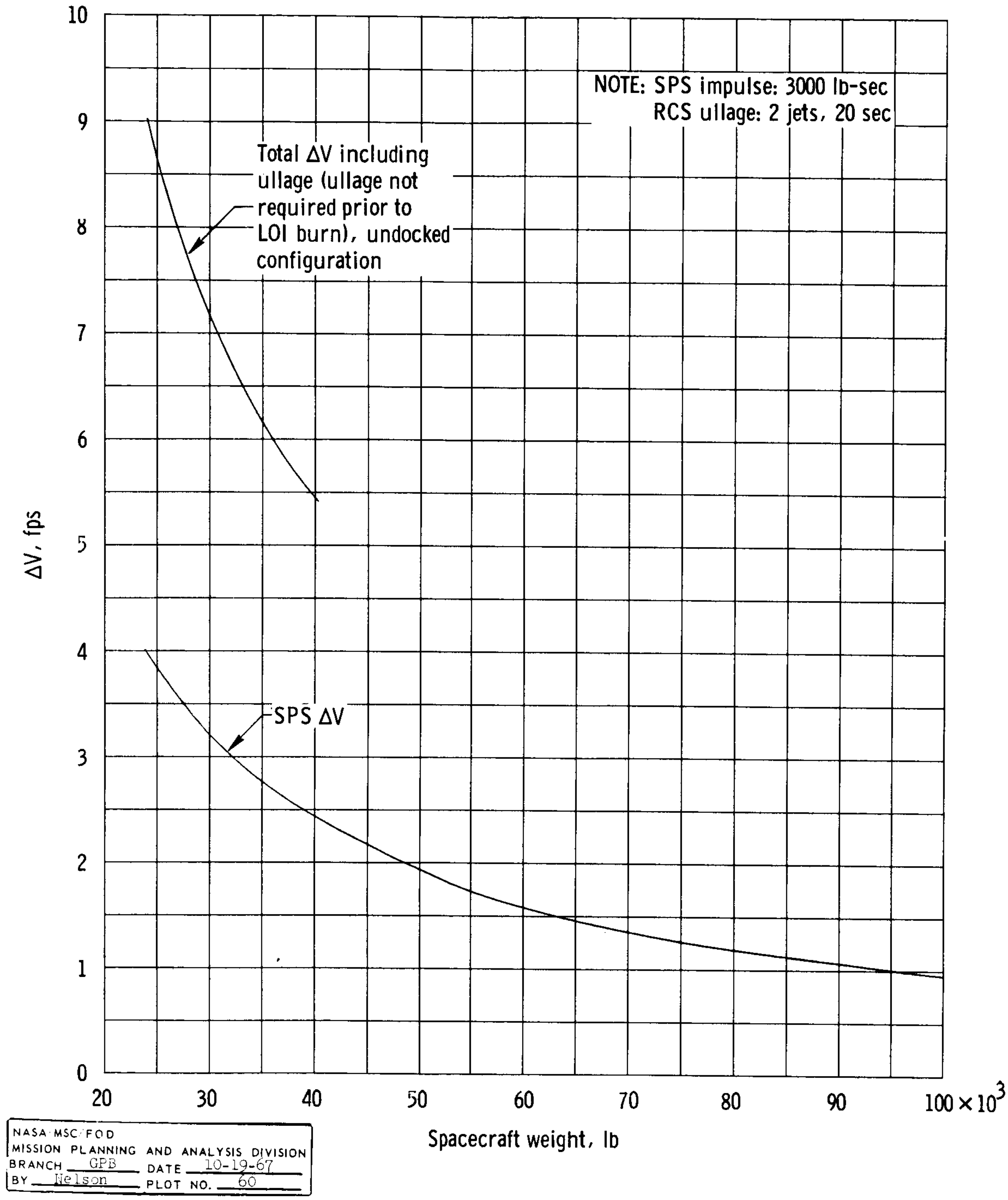

Figure 2.- ΔV for small impulse SPS burn for the lunar landing mission.

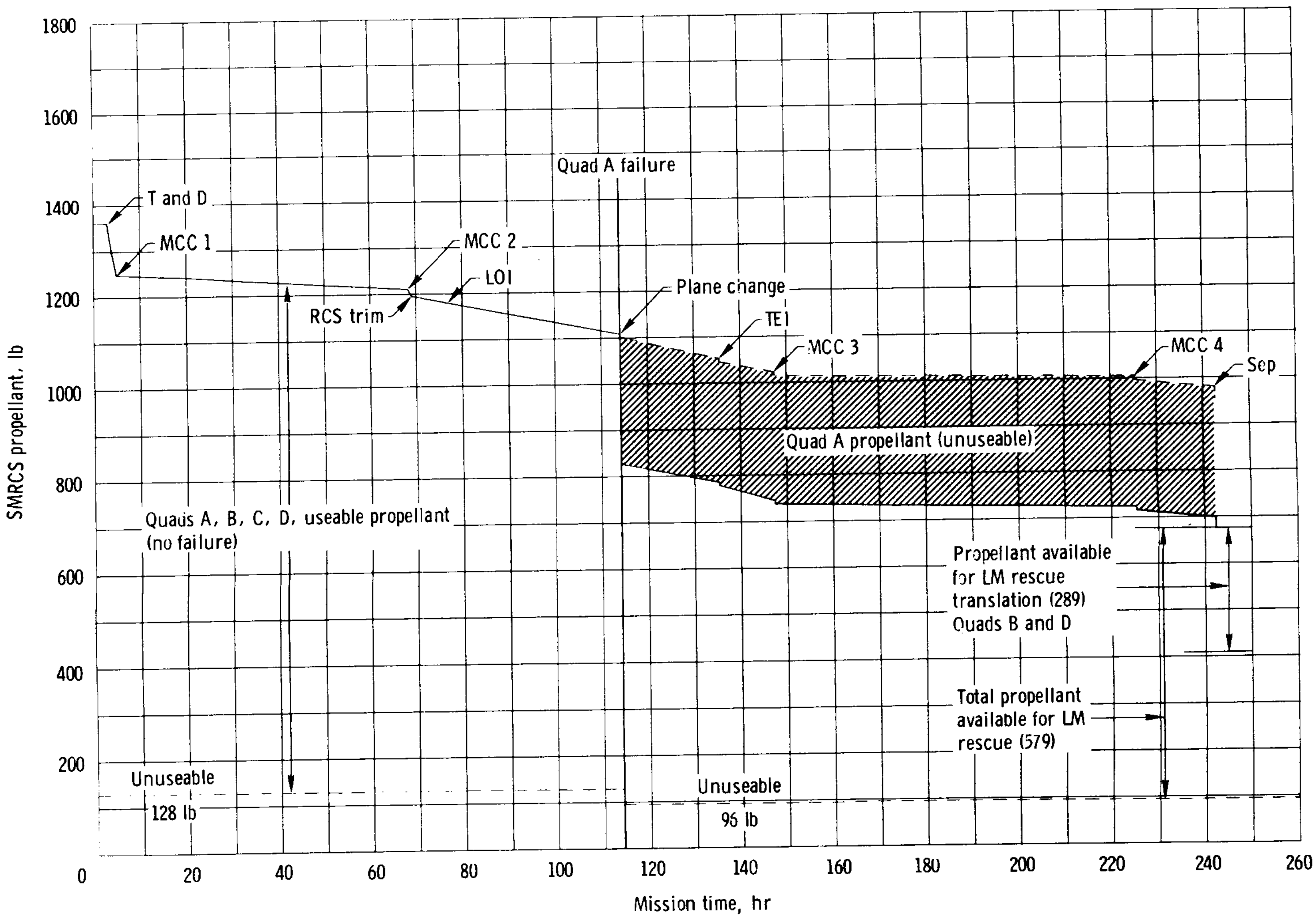

Figure 3 . - Quad failure contingency.

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